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ESTABLISHING A MESH NETWORK WITH BLUETOOTH AND INVESTIGATING THE RANGE ANALYSIS

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Keywords

Bluetooth, Bluetooth Smart, Bluetooth Mesh Networks, Bluetooth Low Energy, Bluetooth Beacons.

Abstract

Bluetooth is an effective technology in short range wireless communications. The standards of Bluetooth have been released by the Bluetooth Special Interest Group (SIG) and the release of Bluetooth Low Energy (LE) standard aka. Bluetooth Smart was one of the breakthroughs concerning Bluetooth. LE offers efficient ways to overcome problems regarding the efficiency and energy consumption. Adopting LE to the Internet of Things (IoT) standards has made LE a more acknowledged technology in the market. But there were some problems such as the limited range, not having the IP support. IP support has been released by SIG to overcome the IP problems, but the range and the topology problem remained until the mesh standard has been released. In this paper, the essentials of a mesh network will be mentioned along with a base application that has been performed in a three-story warehouse. The supplies in the warehouse were assigned a LE Beacon which is a member of the mesh network and the absence or the presence of the supply has been monitored via the mesh network.

BLUETOOTH İLE MESH NETWORK OLUŞTURULMASI VE MENZİL ANALİZİNİN İNCELENMESİ

Anahtar Kelimeler

Bluetooth, Bluetooth Smart, Bluetooth Mesh Ağları, Bluetooth Düşük Enerji, Bluetooth Beacon.

Öz

Bluetooth kısa mesafe kablosuz haberleşmelerde kullanılan etkili bir yöntemdir. Bluetooth Standartları Bluetooth Special Interest Group (SIG) tarafından yayınlanmaktadır. Bluetooth Düşük Enerjinin yayınlanması ile bu teknolojide bir çığır açılmıştır. Düşük enerji, verimlilik ve enerji tasarrufu açısından karşılaşılan problemlere çözümler üretmiştir. Düşük Enerji teknolojisini Nesnelerin İnterneti standardına uyumlu hale getirmek bu enerjiyi daha tanınır hale getirmiştir. Karşılaşılan IP sorunu ve topoloji sorunları SIG tarafından yayınlanan standartlar ile çözüme kavuşturulmuştur. 2017 yılında yayınlanan mesh standard ile Nesnelerin İnterneti ve Bluetooth Düşük Enerji uyumu gerçekleştirilmiştir. Bu çalışmada bir Mesh Ağının genel özelliklerinden bahsedilmiş, daha sonra üç katlı bir depoda bulunan nesnelerin takibinin mesh ağı aracılığı ile gerçekleştirilebileceği gösterilmiştir. Nesnelerimn var veya yok olmaları mesh ağı aracılığı ile takip edilmiştir.

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1. Introduction

Bluetooth can be classified into two categories and these categories are Bit Rate/ Enhanced Data Rate (BR/EDR) and Bluetooth Low Energy (LE). LE has been introduced with the Bluetooth 4.0 standard. Bluetooth LE constitutes an architecture to ensure a low energy data transfer between the devices. This architecture has control and host parts. The control part consists of the physical layer and the host part consists of the layers that belong to LE. The layers that belong to LE are called as Logical Link Control and Adaptation Protocol (L2CAP), Attribute Protocol (ATT), Generic Attribute Protocol (GATT), Security Manager Protocol (SMP) and the Generic Access Profile (GAP) (Bluetooth SIG, 2010).

There are roles attributed to the devices in LE. The most important roles are the scanner role and the advertiser role. The advertiser is supposed to advertise the data that the module is supposed to advertise and the scanner scans for the specific data packets and response to the advertised data that it is scanning for. Another set of roles in LE is called Master/Slave roles. The scanner and the advertiser roles are the roles that a device can have before a connection is established. After the connection is established, the devices work in Master/Slave roles and they can transfer data between them. A master can communicate with up to 8 slaves at the same time. After the 4.0 standard, 4.1 and 4.2 standards were released. These standards were released to enhance the LE technology in terms of mesh adaptation and IoT adaptation, but they do not contain an enhanced data rate and enhanced range capabilities (Martelli, 2014).

In 2016, with the release of the 5.0 standard, the data load and the transmission range has been increased. The 31 bytes of the data capacity of the standard 4.0 has been increased to 255 bytes and the connection speed has been increased to 2Mbps from 1Mbps as well as the range has been doubled (Gomez et al., 2012.)

1.1. Bluetooth Layers

As mentioned above, the LE architecture has layers which performs the low energy data transfer between the devices and these layers are L2CAP, SMP, ATT, GATT and GAP. L2CAP is placed right above the physical layer and it acts as a multiplexer to relay the data do the layers above. It relays the connection oriented and the connectionless data services to the upper layers (Heydon, 2013).

ATT defines the communication between two devices as server and client. The data packets that will be used by the GATT layer are called as “attributes”. The client can have access to the information stored by the server by sending request. And the server can send this information in two different ways which are called as notification and indication. No acknowledgements are required while the server sends data to the client while acknowledgements are required to send the second data packed in indication. Attributes can be classified as readable/not readable and writeable/not writeable (Gomez et al., 2012).

SMP is defined as a layer where the data is encrypted. This makes a connection more secure and reliable. AES-128 encryption is used in SMP and it can also provide some extra protection as Man in the Middle (MITM) (Zheng et al., 2006).

GATT is the layer where the data exchange happens. GATT defines the rules in the data exchange. It is necessary to mention such concepts as service and characteristics while mentioning GATT. A service can be defined as a collection of data such as data obtained from a sensor. There can be custom defined services in LE as well as there are pre-defined services defined by SIG. A characteristic is defined as how the actual data is represented in a service. To distinguish the attributes that belong to services and characteristics, universally unique identifiers (UUID) are used. There are 2 types of UUIDs available, and they are 16-bit UUIDs and 128-bit UUIDs. 16-bit UUIDs are only used in the services and characteristics that are pre-defined by Bluetooth SIG and the 128-bit UUIDs are used in custom services and characteristics (Faragher and Harle, 2014).

And the last remaining layer, GAP, defines roles such as Scanner, Advertiser, Peripheral and Central. With these definitions, it is safe to talk about the communication topologies that are used in LE (Ko et al., 2011). The communication topologies are categorized into three categories which are:

1. Two devices send and receive data simultaneously
2. One device send data to multiple devices (Beaconing)
3. Multiple devices can send and receive data among each other simultaneously (Mesh)

Before Bluetooth 4.0, Topology Number 1 communication was widely used in device to device communications such as it is used in bluetooth mouse and printers. After the release of Bluetooth 4.0, this topology had been

integrated with the low energy communications and used in such applications as health monitoring devices, smart watches and sports equipment. Beaconing allows one device to stream data to many devices. This is used in areas where the static data stream is widely used such as museums, stores and indoor navigation systems. There are many beacon standards that are available to use in the Beaconing mode such as iBeacon and Eddystone etc. Mesh topology is designed for allowing multiple devices to communicate among themselves simultaneously. This will be mentioned in greater detail in the following sections.

1.2. Bluetooth Mesh

After the release of Bluetooth LE, Bluetooth has become more important in short range wireless communications. But even though LE offers a low energy communication with rather cheaper equipment it still lacks the utilities that can overcome the problems that users face in short range wireless communications. And two of the most vital of these problems are; to be able to cover larger physical areas and to be able to interact with larger number of devices (Gogic et al., 2016). By adopting the already existing mesh topology that is used in wireless communications to Bluetooth LE, these problems can be overcome. The Mesh Standards has been released by Bluetooth SIG and The Mesh has been started to be used in LE officially.

1.2.2. Bluetooth Mesh Concepts

Each device in the Mesh Network is called as a node. Bluetooth Mesh enables us to interact with many nodes, even with the nodes that is out of the coverage area of the main node. This is only possible with the aid of the technique that is called “relaying”. Relaying means that an LE node that is in the Mesh Network can both take the data for use or relay the data to other nodes. This way a node can send a message to another node that is not within the reach by using at least one more node as a relay bridge (Maharjan et al., 2014).

There are different methods that are used in Mesh Networks to deliver data packages. The technique that is called as flooding is used in Bluetooth Mesh. Flooding is the technique where the message is received by all nodes in the network. Each message is assigned with a Time to Live (TTL) value and this is used for determining whether the message is to be relayed or nor. Each node has a cache memory, and this is used to determine whether the received message is a new message or an old message. This way the older messages can be ignored(Maharjan et al., 2014).

There are four different types of nodes that can be used in a mesh network and they are called as low energy node, friend node, relay node and proxy node. And it is possible to stream data of 23 bytes (as content) with a mesh network application. A device can be introduced to a mesh network by a process that is called as provisioning. The provisioning is a process where an unprovisioned device undergoes a series of operations to be a member of the mesh network. The process can be classified into five steps. The first step is called as Beaconing. The unprovisioned node sends a specific data structure as a beacon and announces that it is a node ready to be provisioned. The next step is called as invitation. At this step a layer is established between the provisioner and the unprovisioned device. The provisioner invites the unprovisioned device to the mesh network. Then as the next step the public keys are exchanged between the devices. Then the provisioner authenticates the device that is in the provisioning process and lastly the node addresses and the network keys are delivered to the device, which is called as a node of the network after this (Sirur et al., 2015). In this study a mesh network in a warehouse has been established and the tracking of the objects has been performed by this mesh network.

2. Materials and Method

In this study a Bluetooth Mesh Network is established, and a simple and local application has been performed. This application sets a basis for further improvements and implementations and it is open for developments. Bluetooth Beacons that has nRF52832 chips on them have been used in this project. nRF52832 is an ARM Cortex M4F 32-bit processor and it has a 512kB flash memory. It is manufactured by Nordic Semiconductors which is one of the leading Bluetooth IC manufacturers in the world. The software that has been used to program nRF52832 is called Segger EMBEDDED STUDIO and this software provides free license when working with the products of Nordic Semiconductors. The beacon that is used in this application is given in Figure 1.

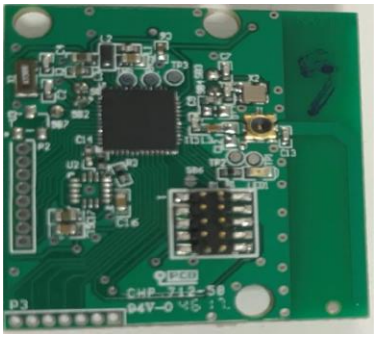

Figure 1. The Nordic nRF52832 Beacon

To show the mesh network works properly, a set of experiments have been set up and the "relaying" ability and the "star topology" has been investigated. For the first part the three modules have been placed as it is given in Figure 2. Each module is within the coverage area of the preceding one and the next one. Each device is placed a hundred meters away from each other so that the distance from the central to the furthermost peripheral is almost 400 meters. The aim is to send data to the furthermost module from the central device by using the intermediate modules for relaying the message. The message has successfully been sent to the furthermost device.

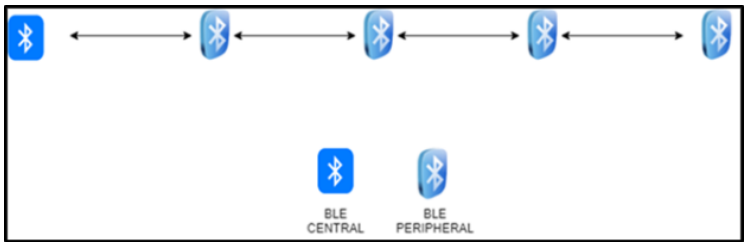

Figure 2. The Setup to Show the Relaying Mechanism

The second setup is to be able to reach to a particular device in the mesh network and make it perform the predefined tasks successfully. For that, a setup containing 7 different modules has been used. One of the modules is a central module and the others are peripheral modules. This setup is shown in Figure 3.

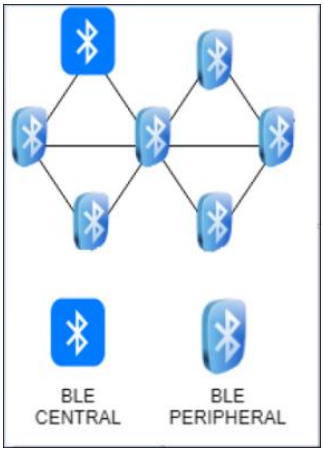

Figure 3. The star Topology

Each device had been assigned an address and the data had been flooded into the mesh network. Although the data had been received by all nodes, only the target node has acted accordingly. This has shown that each node in the mesh network can be reached through the central device and the predefined tasks can be performed successfully.

For Bluetooth communication to be a healthy communication, the RSSI (Received Signal Strength Indicator) should not be less than -90 dBm. It has been observed that for RSSI above -90 dBm there has never been an interruption in the communication. To see how effective the beacons that are used in this system are, the RSSI measurements have been performed for the highest transmit power configuration. Each beacon can have a specific RSSI range due to the antenna structure and design. And the peripherals also affect the received power strength. For the specific beacon that is used in this study which has a PCB antenna, the RSSI measurements have been performed both in indoors and outdoors. Both the outdoor and the indoor measurements have been performed

when the beacon transmit power is adjusted to +4dBm. The graph that is obtained for the outdoor measurement is given in Figure 4.

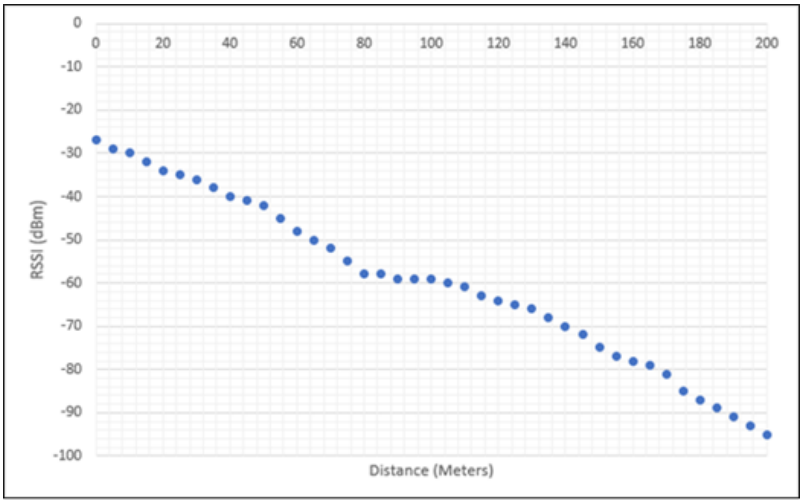

Figure 4. RSSI/Distance Graph in Outdoor Measurements

For the indoor applications there are factors to be considered such as how the concrete in the walls affect the bluetooth signal strength. A strength of a signal over a 30-centimeter-thick wall has been measured by setting up a system as shown in Figure 5.

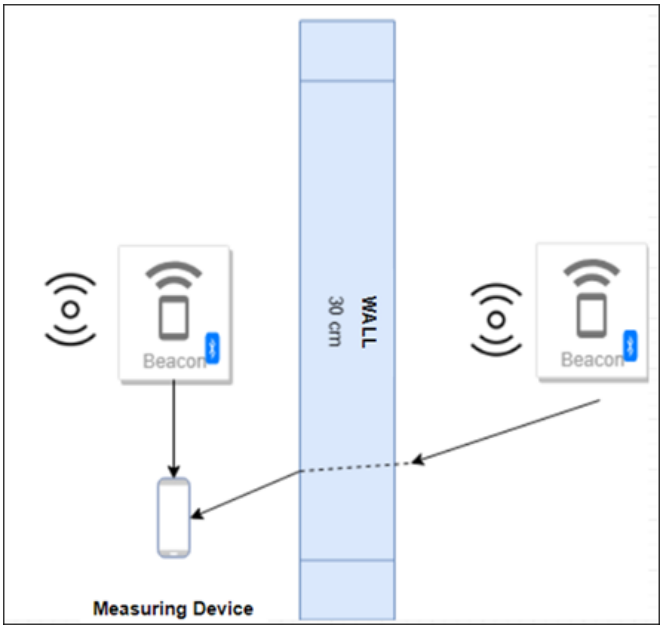

Figure 5. The Setup to Show the effect of Concrete on Bluetooth Signals

The concrete weakens the Bluetooth signals by about 30 dBm as shown in Figure 6. and other peripherals that are made of metals also effect the signal quality. To show the reduction in a better way, the Received Signal Strength Indicator (RSSI) versus time graph has been shown. The fall that is shown in green indicates the power of the Bluetooth signal by the concrete.

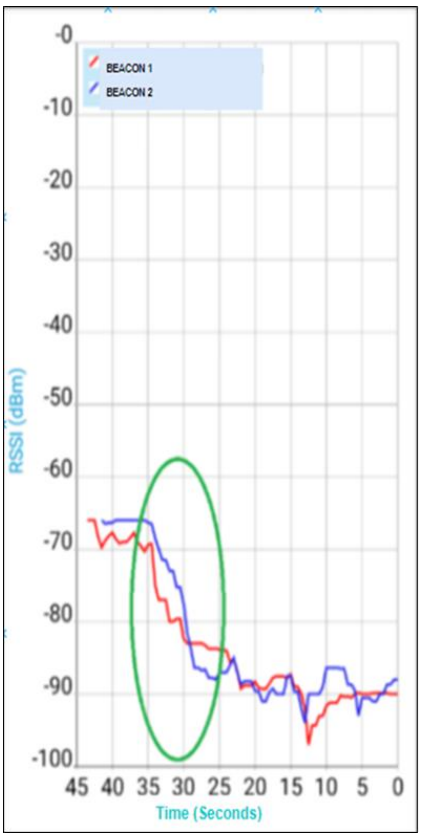

Figure 6. The decrease in RSSI over a wall

For this study, the maximum distance between two beacons is determined to be less than 180 meters for the highest transmit power configuration to maintain a healthy communication in outdoors. In indoors, however, the distance is highly dependent of the structure of the home/office.

For the sake of demonstration, a Bluetooth Mesh network has been developed for a warehouse to perform a simple asset tracking application. In a warehouse with 3 stories that is shown in Figure 7. Six beacons were placed, approximately 10 meters apart from each other to cover the floor grounds and in each floor to ensure full coverage and one extra beacon were placed near the stairs which is shown in red rectangle is placed to ensure that the beacons in different floors are in contact.

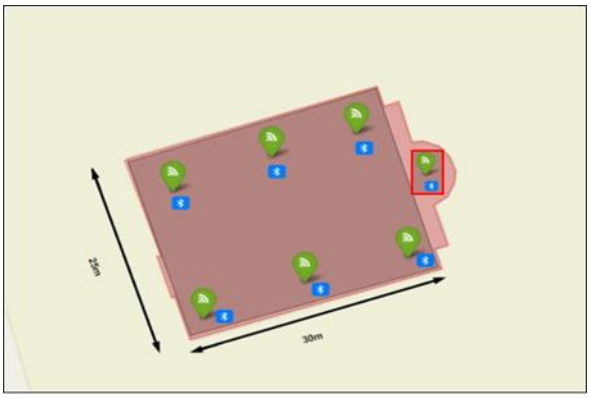

Figure 7. The Warehouse and The Placed Beacons

So, the beacons that is closed to the stairs ensure that the communication will not fail by relaying the content to the upper/lower floor with no loss. The mechanism is shown in Figure 8.

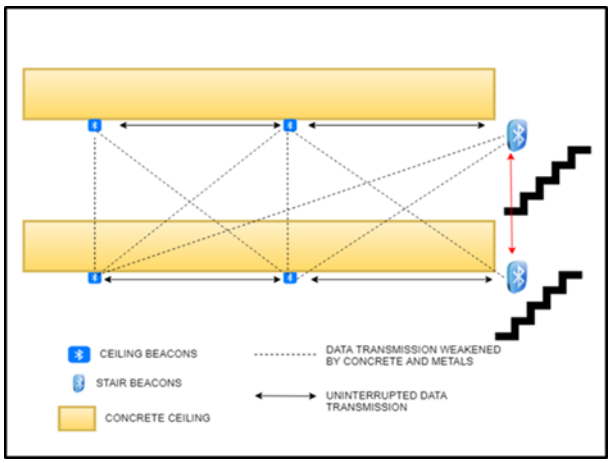

Figure 8. The Interaction of the Modules

The dashed lines indicate the data stream that may be interrupted by the concrete or the peripheral objects that may have high metal density around them. But the straight lines indicate that the modules that are placed in different floors remain in contact regardless of what is going on around them. And the red line indicates that the stair beacons make sure the connection between the floors is kept healthy.

3. Results

To keep track of the contents that are in the warehouse, a bluetooth beacon assigned to each box. 25 boxes were used in this application to see that the system works effectively. Each beacon that is on a box is a member of the mesh network and once it is in the building, the stationary beacons know the presence of the box and inform the computer. Once the box is moved out of the building, the beacon attached to the box is no longer within the boundaries of the mesh network. The mesh network scans for the existent beacons inside the building in every minute and this way it informs the main device and computer.

A meaningful data set has been constructed to be used in the mesh network application. A 8-byte data set has been determined. The first two bytes represent the device ID. Thus, the system supports up to 255 beacons to be monitored but the dataset can be adjusted to support more devices. The next two bytes are for the presence or the absence of the beacon. And the remaining four bytes are reserved in further uses. The first two of the remaining bytes are considered to be used as the exact location information and the last two bytes are reserved for emergency calls (only in the human tracking applications, they will be either left blank or used for other operations in asset tracking applications.)

By using the Health Messages that is in the Bluetooth Mesh Network Specifications (Bluetooth SIG, 2017) it is possible to detect the health of a node in a network and if a node is moved out of the network the health message indicates that the beacon is doesn't exist in the building anymore, thus letting the authorities know about the situation.

4. Discussion and Conclusion

This is an example that sets out a basis for further asset tracking applications with Bluetooth. Before the introduction of mesh networks into the Bluetooth LE, the bidirectional communications among the devices was not possible without connection. And when the master/slave connection topology is concerned, it was only possible to connect at most 8 slaves to one master. In this topology slaves aren't able to talk to each other and they can only communicate with the master. Mesh applications in LE eliminates not only the limitation in the number of supported nodes, but it also enables each individual node to talk to any other individual node as long as there is an uninterrupted communication link between them. Possible and considered improvements on this study that may be conducted in the future are

1. Adding location beacons to the sections of the building floors and letting the beacons that are attached to the boxes work in multiple modes such as mesh network member and LE scanner. This way, we can know the exact location of the box in the building via the mesh network.
2. By using a gateway device that has a LE chip and a wireless module on, we can obtain the data online. And the system can inform the authorities via internet about the activities in a warehouse.

3. This warehouse example can be extended to patient tracking in the hospitals and personal tracking in such places as mines and other places that has risks.

Bluetooth plays an important role in our lives as we embrace the technology more than ever. Using the mesh network applications, the asset and human tracking applications will be easier and practical and more user friendly. Emerging this technology into everyday life will make lives easier

Conflict of Interest

No conflict of interest was declared by the authors.

References

Bluetooth, S. I. G. (2010). Bluetooth core specification version 4.0. Specification of the Bluetooth System.

Bluetooth SIG (2017). Bluetooth URL https://www.bluetooth.org/docman/handlers/downloaddoc.ashx?doc_id=429633&_ga=2.261454788.837700053.1545473305-1030374617.1545473305 Access Date 10.05.2017

Faragher, R., & Harle, R. (2015). Location fingerprinting with Bluetooth low energy beacons. IEEE journal on Selected Areas in Communications, 33(11), 2418-2428.

Gogic, A., Mujcic, A., Ibric, S., & Suljanovic, N. (2016). Performance analysis of Bluetooth Low Energy mesh routing algorithm in case of disaster prediction. Int. J. Comput. Electr. Autom. Control Inf. Eng, 3, 1075-1081.

Gomez, C., Oller, J., & Paradells, J. (2012). Overview and evaluation of Bluetooth low energy: An emerging low-power wireless technology. Sensors, 12(9), 11734-11753.

Heydon, R. (2013). Bluetooth low energy: the developer's handbook (Vol. 1). Upper Saddle River, NJ: Prentice Hall.

Ko, J., Terzis, A., Dawson-Haggerty, S., Culler, D. E., Hui, J. W., & Levis, P. (2011). Connecting low-power and lossy networks to the internet. IEEE Communications Magazine, 49(4)

Maharjan, B.K.; Witkowski, U.; Zandian, R. Tree Network Based on Bluetooth 4.0 for Wireless Sensor Network Applications. In Proceedings of the 6th European Embedded Design in Education and Research Conference (EDERC), Milan, Italy, 11–12 September 2014.

Martelli, F. (2014). Bluetooth low energy. University of Bologna, 25.

Sirur, S.; Juturu, P.; Gupta, H.P. A Mesh Network for Mobile Devices Using Bluetooth Low Energy. In Proceedings of the IEEE Sensors, Busan, Korea, 1–4 November 2015.

Zheng, J., Lee, M. J., & Anshel, M. (2006). Toward secure low rate wireless personal area networks. IEEE Transactions on mobile computing, 5(10), 1361-1373